ECE 495 – Electromagnetic Warfare and Survivability

Block 3: IR EW and Signature Management
Lesson 21: IR/EO Fundamentals

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Where We Left Off

Block 2 fought the threat in the **RF** spectrum: sense its emissions (ES), protect our own (EP), deny its use (EA).

But an RF jammer cannot touch a weapon that listens in a different physics. The terminal-game threat often homes on **heat**.

Block 3 moves into the infrared and optical domain, and the larger problem behind low observability: **managing what you emit and reflect**. For an all-aspect, broadband-LO bomber like the B-21, signature is a first-order survivability driver.

Lesson Objectives

By the end of this lesson, you will be able to:

- Explain why every warm object radiates, and how **temperature** sets both how much it emits and **where** its energy peaks
- Identify the **MWIR** and **LWIR** atmospheric windows and explain why the IR fight lives in them
- Distinguish **reflective-band** sensing (needs illumination) from **emissive-band** sensing (sees the target's own heat)
- Contrast **photon** and **thermal** detectors, and explain why high-performance IR sensors are cooled

Two Ways to Be Seen

Radar sees the energy you *reflect*. An IR sensor sees the energy you *emit*.

- You can shape and coat an airframe to shrink its **RCS** — but you cannot stop it from being **warm**
- IR/EO sensing is **passive**: no warning to the target, hard to jam, very precise in angle
- The price: **line-of-sight only**, and the atmosphere and weather can close the door
- Naturally warm backgrounds are **clutter** — the IR problem is as much background as target

You can hide your reflection. You cannot hide your temperature.

Everything Warm Glows

Every object above absolute zero radiates across a spread of wavelengths. A perfect radiator is a **blackbody**; real surfaces emit some fraction of it, set by their **emissivity**.

Two consequences set up the entire block:

- **Hotter radiates much more.** Total emitted power climbs with the *fourth power* of absolute temperature — double the temperature, radiate roughly **16**$\times$ as much
- **Hotter runs bluer.** The wavelength of peak emission shifts *shorter* as temperature rises

Those two facts — *how much* and *where* — are the whole physics of an IR signature.

Hotter Runs Bluer

Where a source peaks tells you which band sees it best:

Source	Approx. temp	Peak / band
Sun	$\sim$5800 K	$\sim$0.5 μm — visible
Afterburner / rocket plume	$\sim$1000 K	$\sim$3 μm — MWIR
Jet exhaust, tailpipe	$\sim$800 K	$\sim$3.5 μm — MWIR
Aero-heated skin	$\sim$325 K	$\sim$9 μm — LWIR
Airframe / terrain backdrop	$\sim$290 K	$\sim$10 μm — LWIR

Hot, fast-moving parts live in the MWIR; cool skin and the world behind it live in the LWIR. That split drives band choice for the rest of the block.

The Atmosphere Picks the Bands

The target's temperature says where it *wants* to be seen; the atmosphere says where you *get* to look. **Water vapor** and **CO_2** close broad stretches of the IR — notably $\sim$5–8 μm. What is left are the usable **windows**:

Window	**Range**	**Typical use**
VIS / NIR / SWIR	$\sim$0.4–2.5 μm	reflected-light imaging, NVGs
MWIR	$\sim$3–5 μm	hot targets: plumes, engines
LWIR	$\sim$8–12 μm	cool targets: skin, terrain, FLIR

Humidity and weather shrink IR range: the IR advantage is real, but not all-weather.

Reflected Light vs Emitted Heat

- **Reflective band** (∼0.4–3 μm): you see *reflected* light — sun, moon, a laser. Take away the source and you go dark. This is the VIS/NIR/SWIR world of cameras and night-vision tubes.
- **Emissive (thermal) band** (∼3–14 μm): you see the target's *own* radiated heat. No illumination needed — it works in total darkness. This is the MWIR/LWIR world of thermal imagers and heat-seekers.

A thermal sensor lives on **contrast** — the temperature *difference* between target and background. A hot plume on cold sky is trivial; cool skin against sun-warmed desert can disappear at **thermal crossover**.

Paint hides you by day. At night, your heat still talks.

Catching the Photons: Detectors

An IR detector is a transducer: photons in, electrical signal out. Two families dominate:

- **Photon (quantum) detectors** — a photon frees a charge carrier. Fast, sensitive, and *band-selective* by material: **InSb** for MWIR, **HgCdTe (MCT)** for LWIR. The catch: they must be **cooled**, often to $\sim$77 K.
- **Thermal detectors** — absorb energy and sense the temperature rise (the microbolometer). Broadband and **uncooled**: cheaper and smaller, but slower and less sensitive.

Why cool? Warm, a photon detector drowns in its own noise. Cold, the limit becomes the *background* itself — the best a designer can do.

Where This Is Headed: The Heat-Seeker

The threat that turns this physics into a weapon is the **IR-guided missile** — passive, no radar warning, fire-and-forget.

- **Reticle** / **spin-scan seekers** (early): a spinning pattern chops the incoming IR into a signal that encodes *direction* to a bright hot spot. Cheap and effective — and fooled by a brighter spot, i.e. a **flare**.
- **Imaging IR seekers** (modern): a focal-plane array forms an actual *thermal picture* and tracks *shape*. It tells a flare from an aircraft and is far harder to defeat.

L23 dissects seekers, IRST, and FLIR; **L24** covers the counters. For a penetrator, this is the threat the RF jammer cannot reach.

Block 3 Roadmap

- **IR sensing (L21–L23):** blackbody and bands today; IR emitters and the five signature components; then seekers, IRST, and FLIR
- **IR countermeasures (L24):** flares, DIRCM, plume suppression, exhaust mixing
- **RF signature (L25–L27):** RCS physics, faceting and curvature, RAM, EMCON
- **Multi-spectral (L28):** acoustic, visual, and EO signatures, and how they fuse
- **Project 3 (L29–L30):** a B-21 IR/RCS signature trade study — HW3 and Quiz 3 land at L30

Quick Exercise / Type-along: Pick the Band

For each source, decide: which **window** sees it best (VIS, MWIR, or LWIR), and is it **reflective** or **emissive** sensing? Classify each by a show of hands.

1. A fighter in afterburner, climbing at night
2. The B-21's sun-lit upper surface, photographed at noon
3. A cold-soaked airframe gliding over warm desert at dusk
4. A SAM's missile motor at the moment of launch

Today's Interactive Demo: Blackbody Curves

Today's interactive demo.

- Plot the blackbody curve for three temperatures: a plume, the airframe skin, and the sun
- Mark each curve's **peak wavelength** and watch it slide shorter as temperature climbs
- Shade the **MWIR** and **LWIR** windows and see which source lands where
- Read off the takeaway: *which band would you choose to hunt each target?*

Companion script: `L21_PlanckBlackbody.m`

In L22 we turn this physics on the aircraft itself: the five components of an IR signature.

Wrap-Up

Key ideas:

- Radar sees what you reflect; IR sees what you **emit** — and everything warm emits
- Temperature sets *how much* you radiate and *where* you peak: hot $\rightarrow$ MWIR, cool $\rightarrow$ LWIR
- The atmosphere opens only two IR windows worth fighting in: **MWIR (3–5)** and **LWIR (8–12 μm)**
- Thermal sensing runs on **contrast**; high-performance detectors are **cooled** to get there

Next lesson:

- **L22: IR Emitters** — the five components of an aircraft's IR signature
- Pre-flight quiz for L22 due before class